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Effect of Void Fraction and Interstitial Air Pressure for Flow Properties of Cohesive Fine Powder

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Abstract

This study experimentally investigated the flowability and floodability using the discharge of the cohesive fine powder from an orifice when air was supplied from the top and the bottom of powder bed in a vessel. We discussed the beginning of the powder discharge and the flow of powder during the stable discharge because of the evaluation of flow properties of the cohesive fine powder. Two Ca(OH)_2 powders were used in this study, where the mean particle diameter and the particle density were almost same. The flowability and floodability of these powder by the powder tester were almost identical value. As the experimental conditions, the initial void fraction and the volumetric flow rate of air at the top and bottom were changed. The stable discharge of two Ca(OH)_2 powder was obtained as the same flow rate of air was simultaneously supplied at the top and the bottom of the powder bed as well as the previous study. When the initial void fraction on each Ca(OH)_2 powder was high, the continuous discharge was obtained on the low interstitial air pressure. On the other hand, the interstitial air pressure at the beginning of the powder discharge of Ca(OH)_2 B was lower than that of Ca(OH)_2 A when the initial void fraction of each powder was the same value. This result indicated that Ca(OH)_2 B can be easily discharge by the flow of air as compared with Ca(OH)_2 A. Therefore, we inferred that the flowability of Ca(OH)_2 B was high. The high averaged interstitial air pressure was required to obtain the same mass flow rate when the initial void fraction of same particle was low. In addition, the mass flow rate of Ca(OH)_2 B was higher than that of Ca(OH)_2 A when the initial void fraction and the averaged interstitial air pressure were almost same value. We can be considered that the continuous discharge of the cohesive fine powder represented the flushing of powder. Therefore, this result supposed that the floodability of Ca(OH)_2 B was high as compared with Ca(OH)_2 A.

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Keywords: Cohesive powder, Flowability, Floodability, Particle properties, Void fraction, Interstitial air pressure ;

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1. Introduction

The cohesive fine powder is widely used in an application of various industries because it has the superior reaction on the large specific surface area. However, the handling of the cohesive fine powder in the air is difficult extremely to the effect of the cohesive force. When the cohesive fine powder is discharged from an orifice on a vessel, a cohesive arch or bridge is encountered, and the sudden discharge of the cohesive fine powder from a gap occurs [1]. These phenomena are the troubles in the powder handling device and these problems need to avoid. Therefore, the various operations to the powder discharge were proposed such as the air flow, the vibration and the mechanical feeder. We examine the powder discharge from an orifice using the air flow because the handling of the cohesive fine powder in the air is complicated. If the cohesive fine powder can easily discharge from an orifice on a vessel using air flow, then this operation is used in the application of powder handling system.

There are many experimental and theoretical studies on the flow characteristics of the powder discharge through an orifice using the air flow [2-11]. These studies can be divided by the location of the supply section of air and the powder properties. In addition, according to Geldart classification [12-13], they said that the cohesive force on the particle depends mainly on the particle diameter, which is called the group C particle. We generally recognize that the stable discharge of Geldart C particle from an orifice using the flow of air is difficult. Most of previous studies [2-7] investigated the group B and D particle of a large particle diameter in Geldart classification. In addition, there are studies [7-11] on the flow of the powder discharge from an orifice on the group A and C particle of a small particle diameter. In particular, the discharge of the group C particle is difficult, and that is confirmed unsteady flow [9-11]. Furthermore, it was hardly seen the study of the discharge of the powder from an orifice in a vessel on the group A and C particles when the air was supplied simultaneously at the top and the bottom of the bed. Therefore, we can recognize that the examination of the discharge of the cohesive fine powder using the air flow was not enough.

The previous studies [14-16] investigated the flow of the group A and C particle through an orifice on the flat bottom. We found that the continuous discharge of the cohesive powder obtained when the same flow rate of air was supplied at the top and the bottom of the powder bed in a vessel, and discussed about the different flow pattern of the bed depend on the location of the injected air. The void fraction and interstitial air pressure have influenced the beginning of powder discharge from an orifice and the continuous discharge such as the mass flow rate of powder. However, the cohesive fine powder could not discharge by our method using the flow of air when the effect of the cohesive force was strong. Here we noticed that the flow of cohesive fine powder and air during the powder discharge was influenced greatly to the void fraction and the force of acting on the particle. Therefore, we thought that it is necessary to evaluate the flow in consideration of these influences.

In this study, we evaluated the flowability and floodability of the cohesive fine powder belong to the group C particle in Geldart classification using the discharge device from an orifice of the cohesive fine powder when the air was supplied simultaneously at the top and the bottom of the powder bed in a vessel. The powder used was two Ca(OH)_2 , which are almost identical value of the particle diameter, the particle density and the index of flowability and floodability. We examined the effect of the initial void fraction and the interstitial air pressure against the beginning of the powder discharge and the continuous powder discharge.

Nomenclature

D	Orifice diameter (mm)
d	Particle diameter (m)
H_i	Initial height of powder bed in a vessel (mm)
M_p	Mass of discharged powder (g)
m_p	Mass flow rate (g/s)
p_a	Interstitial air pressure (Pa)
p_{avg}	Averaged interstitial air pressure (Pa)
Q_h	Flow rate of air at the bottom of powder bed (m^3/s)
Q_t	Flow rate of air at the bottom of powder bed (m^3/s)
t	Elapsed time (s)
ε_i	Initial void fraction (-)

ρ_p Particle density (kg/m³)

2. Experiment

Fig.1 shows a schematic diagram of the experimental apparatus that consists of the packing part of the cohesive fine powder and the supply section of air at the top and the bottom of vessel. The packing part of the powder was made to the acrylic pipe where the inside diameter D_v is 50mm and the height is 150mm. The air distributors were arranged in the top and the bottom of a cylindrical vessel. The air through the distributors was supplied simultaneously to the powder bed in a vessel. The powder was discharge from a circular orifice at the bottom of bed, which is located in a center. A circular orifice diameter D was fixed 4mm in this study. The flow rate of air was adjusted by the mass flow controller. The mass of the discharge powder through an orifice M_p was measured by the load cell on a receiving vessel. The interstitial air pressure at the top of the powder bed p_a was measured to the pressure sensor, which is located on 150mm from the bottom of vessel. The state of flow of cohesive powder bed was recorded by the digital video camera. The height of the powder bed H was measured by the recorded image.

Table 1 shows the particle properties in the present study. The powder used was Ca(OH)_2 powder where the particle diameter and particle density were almost same values. In addition, the flowability and floodability of both particles were nearly identical, which measured by the powder tester. This powder belongs to the group C particle in the Geldart classification. Tables 2 and 3 indicate the experimental conditions in this study. The initial mass of powder M_{pi} was fixed 70g. In these tables, Q_t and Q_b were the flow rate of air at the top and the bottom of the cohesive powder bed, respectively. The initial height of the powder bed H_i changed the adjustment of the initial void fraction. The initial void fraction ε_i was estimated by the initial state of the cohesive powder bed in a vessel M_{pi} , H_i , D_v and ρ_p as the following equation.

$$\varepsilon_i = 1 - \frac{\rho_b}{\rho_p} = 1 - \frac{4M_{pi}}{\pi D_v^2 H_i \rho_p} \quad (1)$$

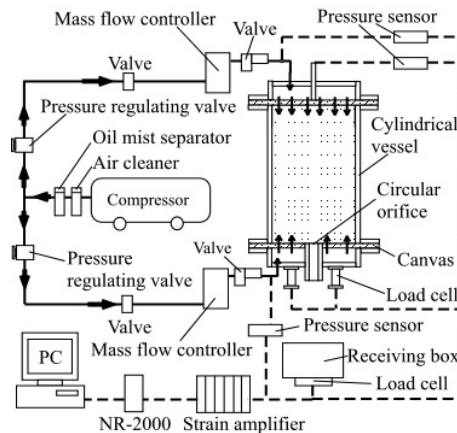


Fig. 1. Experimental apparatus.

Table 1. Particle properties of Ca(OH)_2 .

Particle	d_p (μm)	ρ_p (kg/m ³)	Flowability index	Floodability index
Ca(OH)_2 A	9	2240	23	56
Ca(OH)_2 B	7	2240	21	53.5

Table 2. Experimental conditions of Ca(OH)_2 A.

M_{pi} (g)	H_i (mm)	ε_i	$Q_t=Q_b$ ($\times 10^{-5} \text{m}^3/\text{s}$)	Q_{it} ($\times 10^{-5} \text{m}^3/\text{s}$)
70	97~101	0.812~0.819	0.067~1.667	0.133~3.333

70	87	0.788	0.167~1.667	0.333~3.333
70	75	0.747	0.833~3.0	1.666~6.0

Table 3. Experimental conditions of Ca(OH)_2 B.

M_{pi} (g)	H_i (mm)	ε_i	$Q_t=Q_b$ ($\times 10^{-5} \text{m}^3/\text{s}$)	Q_{it} ($\times 10^{-5} \text{m}^3/\text{s}$)
70	85~88	0.782~0.791	0.067~1.667	0.133~3.333
70	75	0.747	0.333~4.0	0.666~4.0

3. Results and discussions

Fig.2 shows the time histories of the mass of the discharged cohesive fine powder from an orifice M_p and the interstitial air pressure on the cohesive powder bed p_a where the powder used was Ca(OH)_2 A in Table 1, the initial void fraction $\varepsilon_i=0.817$ and the flow rate of air at the top and the bottom of the powder bed $Q_t=Q_b=1.667 \times 10^{-5} \text{m}^3/\text{s}$. We confirmed that the powder discharge from an orifice began when an arbitrary interstitial air pressure acted on the powder bed. The interstitial air pressure was increased rapidly after the air supply, and it maintained the high pressure during the powder discharge from an orifice. We verified that this powder could be discharged continuously, and that the gradient of the mass of discharged powder was almost constant. This stable powder discharge appeared to the previous our study using the Geldart C particle [16]. As Ca(OH)_2 B in this study, the profiles of the mass of the discharged powder and the interstitial air pressure were almost same when the cohesive powder discharged continuously.

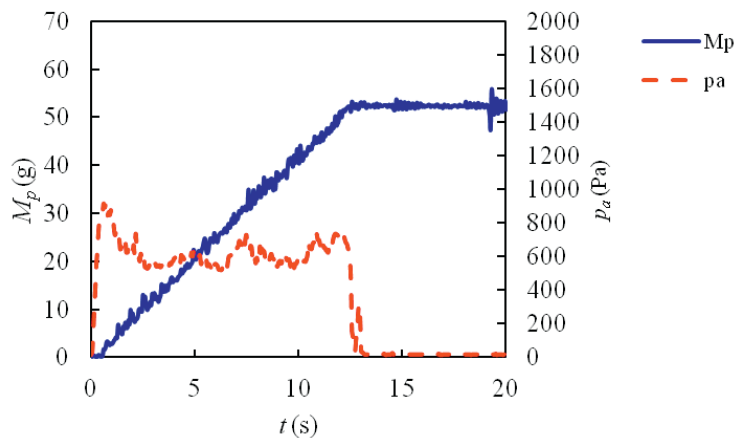


Fig. 2. Time histories of the mass of the discharged powder from an orifice and the interstitial air pressure on the powder bed where the powder used is Ca(OH)_2 A, $\varepsilon_i=0.817$, $Q_t=Q_b=1.667 \times 10^{-5} \text{m}^3/\text{s}$.

Fig.3 shows the relationship between the total mass of the discharged powder through an orifice M_{pt} and the total flow rate of air Q_{it} where the powder used and initial void fraction were changed. The total flow rate of air is the sums of the flow rate of air at the top and the bottom. From this figure, we noticed that the cohesive power of each initial void fraction could not discharge when the total flow rates of air were few. Further, the total mass of the discharged powder from an orifice increased generally with increasing the total flow rate of air. On the other hand, the total mass of discharged powder was decreased with the decrease in the initial void fraction when the total flow rate of air was the same value. However, the evaluation of the flow of the cohesive fine powder was difficult because the distributions of total mass of discharged powder against the total flow rate of air were fluctuated. Therefore, we investigated the relationship between the mass of the discharged powder and the interstitial air pressure.

Fig.4 shows the time histories of the mass of the discharged powder through an orifice M_p where the initial void fraction was a constant, and the flow rate of air at the top and the bottom of the powder bed was varied. We were able to do the judgment of the discharge of the cohesive fine powder from this figure. The judgment of the cohesive powder discharge was defined as follows [16]. When the cohesive fine powder discharged continuously and that gradient maintained a linear profile as shown in Fig.4, the discharge of the powder was possible. This flow of the cohesive fine powder was called Yes discharge. When the cohesive fine powder discharged for a split second, and then the discharge of the powder was stopped, this flow judged with the transient region of the powder discharge, that is, Yes/No discharge. When the discharge of the cohesive fine powder was impossible, it was judged as No discharge. These flows appeared to each experimental condition on two Ca(OH)_2 powder.

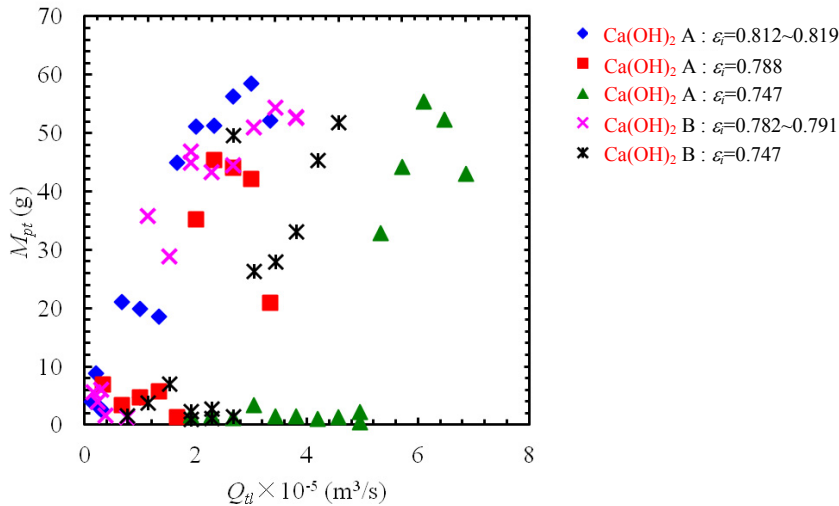


Fig. 3. Relationship between the total mass of discharged powder through an orifice and the total flow rate of air.

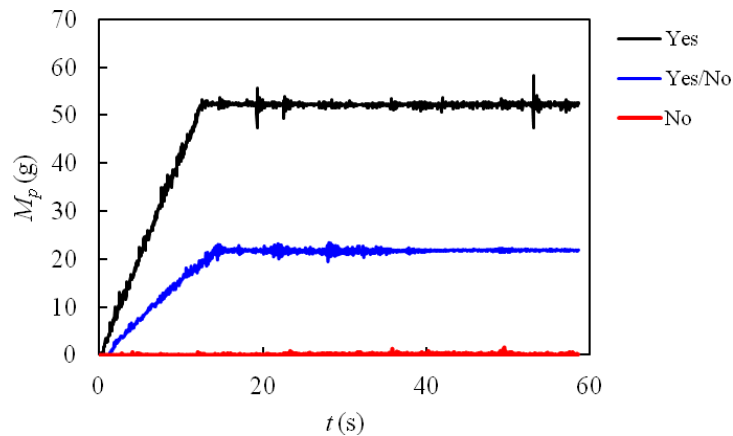


Fig. 4. Judgement of the discharged cohesive fine powder where the powder used is Ca(OH)_2 A, $\varepsilon_i=0.813$, Q_i and Q_b were varied.

Fig.5 shows the relationship between the interstitial air pressure at the beginning of the cohesive powder discharge from an orifice p_s and the initial void fraction ε_i where the data of Yes and Yes/No discharge on two Ca(OH)_2 were plotted. The judgement of the powder discharge was determined by the definition in Fig.4. When the initial void fraction on each powder was high, the continuous discharge of the cohesive fine powder was obtained on the low interstitial air pressure. In the case of the low initial void fraction, the high interstitial air pressure was needed to the beginning of the cohesive powder discharge. On the other hand, we found that the interstitial air pressure at the beginning of the powder discharge of Ca(OH)_2 B was lower than that of Ca(OH)_2 A when the initial void fraction of each particle was the identical value. In Table 1, the particle properties of both particles were almost similar such as the particle diameter, the particle density and flowability. However, this result suggested that Ca(OH)_2 B can be easily discharge by the flow of air as compared with Ca(OH)_2 A. Therefore, we inferred that the flowability of Ca(OH)_2 B was high to that of Ca(OH)_2 A.

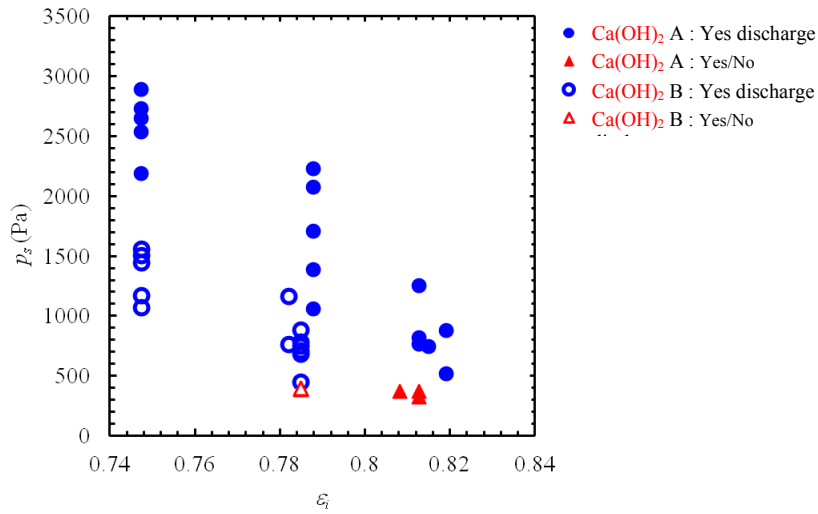


Fig. 5. Relationship between the interstitial air pressure at the beginning of the powder discharge from an orifice and the initial void fraction.

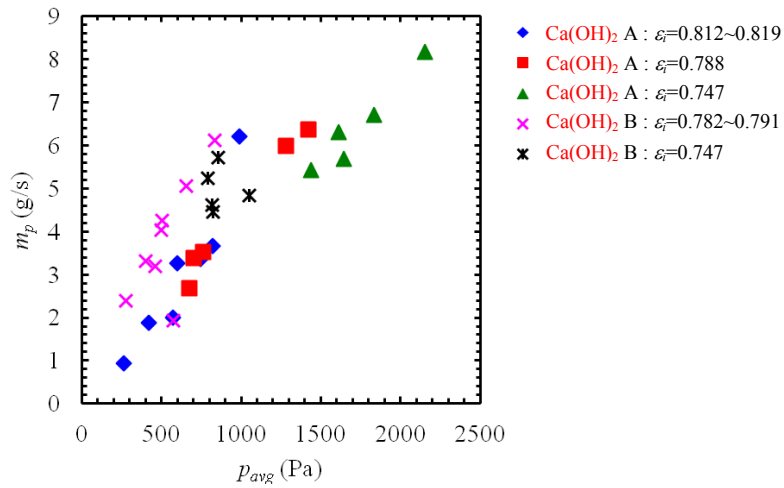


Fig. 6. Relationship between the mass flow rate of powder and the averaged interstitial air pressure.

Fig.6 shows the mass flow rate of the cohesive fine powder through an orifice m_p and the averaged interstitial air pressure during the continuous discharge of the cohesive powder p_{avg} where the initial void fraction of each particle was changed. The mass flow rate of the cohesive powder was calculated from the data of a constant gradient of the mass during the continuous powder discharge in each experiment as confirmed in Fig.2. The averaged interstitial air pressure was also calculated by the data of the pressure during a constant gradient in the powder discharge. In this figure, the mass flow rate of each experimental condition was increased gradually with increasing the averaged interstitial air pressure. Further, when the initial void fraction of an identical particle was low, the high averaged interstitial air pressure was required to obtain the same mass flow rate. In addition, we noticed that the mass flow rate of Ca(OH)_2 B was higher than that of Ca(OH)_2 A when the initial void fraction and the averaged interstitial air pressure were almost same value. As above mentioned, the particle properties of both particles were almost similar as shown in Table 1. Here, we can be considered that the continuous discharge from an orifice of the cohesive fine powder by the flow of air was similar to the flushing of powder from a clearance. Therefore, this result supposed that the floodability of Ca(OH)_2 B was high as compared with Ca(OH)_2 A particle.

4. Conclusion

We experimentally examined the flowability and the floodability of the powder flow including air using the discharge of the cohesive fine powder through an orifice when the air was supplied simultaneously at the top and the bottom of the powder bed. The powder used was two Ca(OH)_2 powder belongs to the group C particle in Geldart classification. The particle properties of these powders were almost identical value such as the particle diameter, the particle density and the index of flowability and floodability. When the initial void fraction of the cohesive fine powder in a vessel and the flow rate of air at the top and the bottom of the powder bed were changed, the mass of the discharged powder from an orifice and the interstitial air pressure were measured. The mass flow rate of the cohesive fine powder was estimated by the measurement data of the mass of the powder discharge. We evaluated the flowability and floodability by the interstitial air pressure on the beginning of the powder discharge and the mass flow rate of powder. These examinations were obtained the following results.

When the initial void fraction on each Ca(OH)_2 powder was high, the continuous discharge of the cohesive powder was obtained on the low interstitial air pressure. On the other hand, the interstitial air pressure at the beginning of the powder discharge of Ca(OH)_2 B was lower than that of Ca(OH)_2 A when the initial void fraction of each powder was the same value. This result indicated that Ca(OH)_2 B can be easily discharge by the flow of air as compared with Ca(OH)_2 A. Therefore, we inferred that the flowability of Ca(OH)_2 B was high to that of Ca(OH)_2 A.

The mass flow rate of powder in each experimental condition was increased gradually with increasing the averaged interstitial air pressure. Further, the high averaged interstitial air pressure was required to obtain the same mass flow rate when the initial void fraction of same particle was low. In addition, the mass flow rate of Ca(OH)_2 B was higher than that of Ca(OH)_2 A when the initial void fraction and the averaged interstitial air pressure were almost same value. We can be considered that the continuous discharge of the cohesive powder represented the flushing phenomenon of powder. Therefore, this result supposed that the floodability of Ca(OH)_2 B was high as compared with Ca(OH)_2 A.

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